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U.E.R
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Institut National
de Physique Nucléaire
et
de Physique des Particules

Bâtiment 200 - 91405 ORSAY Cedex

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J. Badier⁴, C. Bemporad⁶, J. Boucrot⁵, O. Callot⁵, Ph. Charpentier¹,
A.M. Cnops⁶, M. Crozon³, P. Delpierre³, J.F. Detoeuf¹, G.R. Giannini⁶,
R. Hammarstrom², P. Lariccia⁶, R. Lorenzi², J. Mas³, A. Michelini²,
A.Tilquin^{2,3}, J.K. Walker^{5*}

- 1) CEN, Saclay, France
- 2) CERN, Geneva, Switzerland
- 3) Collège de France, Paris, France
- 4) Ecole Polytechnique, Palaiseau, France
- 5) Laboratoire de l'Accélérateur Linéaire d'Orsay, France
- 6) Università di Pisa and INFN, Pisa, Italy

ABSTRACT

We present a measurement of the particle flux punching through tungsten and iron beam dumps ; the NA3 spectrometer was used. Momentum spectra and spatial distributions were determined for pions above 3 GeV/c and for strange particles ($K^\pm$, K_S^0 , Λ , Ξ ; $15 < p < 50$ GeV/c). Information on the effective attenuation length for strange particles were obtained by comparing the results from dumps of different lengths (200 and 220 cm).

* Permanent address : Fermilab. P.O.Box 500, Batavia, IL 60510 (USA)

1. SET-UP

This measurement was made during the so-called NA3 "gluino" experiment in Summer 1984 (ref.1). The goal was to look for new penetrating unstable particles with lifetimes from 10^{-10} to 10^{-8} s. The set-up was a modified version of the NA3 dimuon spectrometer which has been described in detail in ref.2, and is shown on Fig.1.

Relevant features were :

a) a 300 GeV negative pion beam (H8 in the SPS north area at CERN). This beam contains less than 1 % K^- (tagged by two CEDARs) and less than 0.1 % $\bar{p}$. We ran at an intensity of $10^7 \pi^-/\text{burst}$,

b) the dump is shown in detail on Fig. 2. It is made of iron, with a tungsten core. The diameter of the tungsten core increases along the beam to cover a cone of 20 mrad aperture ; no target was placed in front of it. We also took data with a 220 cm dump ; in this case the dump was moved upstream and an identical 20 cm block was added at the end,

c) outgoing particles were measured by a MWPC spectrometer, with a 2.8 Tesla-meter bending power. The trigger was provided by scintillation counter hodoscopes, placed at the entrance and exit windows of the vacuum tank in which particles might decay (See Fig.1 and Ref. 3 for details).

The acceptance was computed for different particles : it is always quasi-independent of the laboratory angle between 0 and 80 mrad (results are only given in this domain), and increases smoothly with momentum for strange particles. We use the following mean values : 45 % for charged K, 70 % for K_S^0 , 50 % for Λ , 40 % for Ξ , and 100 % for pions.

2. TRIGGER AND DATA TAKING

Two types of data were collected under two different trigger conditions.

2.1 Nonstrange meson data

We used a very loose trigger : $T_0 \cdot \bar{H} \cdot (T_1 + T_2)$, this means one particle incident upon the dump, no halo, at least one charged particle in T_1 or T_2 . The trigger selects charged particles (or neutrals if they decay into charged

particles before reaching T_2). Since the counting rate was very high, we took data at a low beam intensity (by closing the beam line collimators) or at the normal beam intensity (by adding a 1 ms deadtime after each trigger). The total integrated beam flux was obtained by counting the number of K_S^0 , and by using the K_S^0 rate measured through the unstable particle data set ; it turned out to be equal to $(46 \pm 8) 10^6$ incident pions.

2.2 Unstable particle data

The trigger required a change of the charged multiplicity in the vacuum tank. We used a "neutral" trigger ($T_0 \cdot \bar{H} \cdot \bar{T}_1 \cdot T_2 \cdot CH3 \geq 2$) and a "charged" trigger ($T_0 \cdot \bar{H} \cdot (T_1=1) \cdot T_2 \cdot CH3 \geq 3$). The particles are identified using the electromagnetic calorimeter (for electrons), a μ -hodoscope and two multicellular Cerenkov counters. A multiple vertex search was performed, and we kept only events with at least one vertex in the vacuum tank. This set of data essentially contains known unstable particles (K_S^0 , $K^\pm$, Λ and E). The total integrated flux is equal to $(1.84 \pm .03) 10^{11}$ incident pions.

A third set of data was obtained with a longer beam dump (220 cm) and by using the same trigger and analysis. The corresponding total integrated flux is equal to $(2.47 \pm .05) 10^{11}$ incident pions.

3. NON STRANGE PARTICLES PUNCH-THROUGH

We used the first set of data for this non strange particle search. The main analysis problem is the pion/muon identification ; as can be easily computed, about 3 % of the pions decay along the 500 m beam line. This implies that the beam spot may contain about one percent of muons, which will simulate pion punch-through. Unfortunately, the muon hodoscope has a hole around the beam line, so we are unable to identify pions and muons in the beam. Comparing the two conditions of data taking (low or high flux + beam time), we find that, at low flux, the counting rate is sensibly higher for high energy particles, indicating an increase in the muon content of the beam in this condition.

Fig. 3a shows the negative and positive momentum spectra. The peak near 300 GeV in the negative spectrum is mainly due to beam muons, produced by π decay in the beam line. The positive to negative ratio is shown in Fig. 3b ; its clear decrease at high momenta reflects the expected leading particle effect.

The "direct" punch-through rate (probability that an incident pion does not interact in the dump) can be computed using data from ref. 4. The π^- absorption cross-section is about 1350 mb/nucleus in tungsten. This gives a non-interaction probability of about $4 \cdot 10^{-8}$, much lower than the observed rates ; the observed pions are mainly produced in the hadronic shower development.

4. STRANGE PARTICLE RATE

Using the second set of data, we measured the rate of unstable particles decaying in the vacuum tank. Fig. 4 shows the $\pi\pi$, $p\pi$, 3π , and $\Lambda\pi$ mass spectra for events with an identified vertex in the vacuum tank. A clean K_S^0 , Λ , $K^\pm$ and Ξ signal is seen. In order to obtain the rate of these particles at the exit of the dump, we have to correct for the branching ratio in the observed channel, and to weigh each event with its decay probability in the vacuum tank fiducial volume. For the Ξ particle this weight takes also into account the probability that the Λ decays in the vacuum tank.

Due to acceptance limitations, results are only given in the momentum range 15 to 50 GeV. Table 1 summarizes the number of events and rates obtained by the first and second data sets.

Fig. 5 shows the momentum spectra for the most abundant particles. One can notice that relative yields greatly depend on the particle momentum (e.g. $K_S^0/\pi^- = .024$ between 15 and 20 GeV and .007 between 40 and 50 GeV).

5. SPATIAL DISTRIBUTIONS

We examine now the spatial distributions of π , K_S^0 and Λ . Fig. 6 shows dN/dR^2 , where R is the distance between the particle and the beam exit point

at the end of the dump. The tungsten plug has a radius of 4 cm at this point. For pions, we see a clear peak at $R = 0$. The tail for $R > 4$ cm contains only 42 % of the particles. The K_S^0 and Λ distributions show a very different behaviour ; here, 83 % of the particles are in the tail, but the ratio tail/total depends strongly on the momentum (see Table 2). We can then distinguish two components : a "small angle" component, with a momentum spectrum similar to the one of pions and a "large angle" component with a faster decrease as a function of momentum. Due to the inhomogenous structure of the dump, the "large angle" component is less absorbed (path mainly in iron) than the "small angle" component (path mainly in tungsten) ; it is not possible therefore to determine the particle production angular distribution.

6. EFFECTIVE ATTENUATION LENGTH

By using the second and third data sets, we measured the effects of adding 20 cm to the dump length. Corrections were introduced for particle decays in the added 20 cm dump length. The corrected mean rate ratios $\text{Rate (220 cm)}/\text{Rate (200 cm)}$ are given in Table 3. They are compatible for K_S^0 , $K^\pm$ and Ξ , while somewhat lower for Λ . Fig. 7 shows the ratio for K_S^0 , as a function of the radius R ; this figure shows clearly the difference between a path in iron and one in tungsten. The average ratio is .42 for $R < 3$ cm, and .55 for $R > 5$ cm. This corresponds to an "effective" attenuation length of 23 cm in tungsten and 33 cm in iron for K_S^0 . They are not real attenuation lengths, due to particle production in the extra 20 cm of material.

CONCLUSION

We have measured the rates and distributions of particles punching through a 200 cm beam dump. Results concern $\pi^\pm$, $K^\pm$, K_S^0 , $\Lambda + \bar{\Lambda}$, Ξ^- and Ξ^+ . These measurements will be useful to check hadronic shower Monte Carlo programs, and for other beam-dump experiments, for instance dimuon experiments and neutrino beam lines.

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REFERENCES

- [1] J. Badier et al., Proposal CERN/SPSC/P-197, March 1984 (unpublished)
- [2] J. Badier et al., N.I.M. 175 (1980) 319.
- [3] J. Badier et al., "Search for new massive particles", to be published.
- [4] A.S. Carroll et al., Phys. Lett. 80B (1979) 319.

TABLE 1
Statistics and rates for all particles

Particle	Decay Channel	Events	Weighted events	Branching ratio	Flux	Acceptance	rate (10^{-8})
$\pi^- (+\mu^-)$	-	2647	2647	1.	$4.6 \cdot 10^7$	1.00	57.5
$\pi^+ (+\mu^+)$	-	1914	1914	1.	"	1.00	42.
K_S^0	$\rightarrow \pi^+ \pi^-$	80310	185910	.686	$1.84 \cdot 10^{11}$	.70	2.1
K^+	$\rightarrow \pi^+ \pi^+ \pi^-$	183	17170	.0559	"	.45	3.8
K^-	$\rightarrow \pi^+ \pi^- \pi^-$	62	5700	.0559	"	.45	1.3
Λ	$\rightarrow p \pi^-$	4870	11520	.642	"	.50	.19
$\bar{\Lambda}$	$\rightarrow \bar{p} \pi^+$	1070	2530	.642	"	.50	.042
Ξ^-	$\rightarrow \Lambda(p\pi)\pi^-$	94	324	1.*.642	"	.40	.007
Ξ^+	$\rightarrow \bar{\Lambda}(\bar{p}\pi)\pi^+$	38	100	1.*.642	"	.40	.002

TABLE 2
Ratio between tail ($R > 4$ cm) and total

Momentum (GeV)	K_S^0	Λ	π
15 - 20	.88	.87	.60
20 - 30	.84	.82	.38
30 - 40	.70	.67	.20
40 - 50	.51	.50	.20

TABLE 3
Corrected relative yields 220 cm/200 cm

K_S^0	.513 $\pm$.003
K^+	.50 $\pm$.06
K^-	.47 $\pm$.09
Λ	.43 $\pm$.01
$\bar{\Lambda}$	.45 $\pm$.02
Ξ	.51 $\pm$.09
Ξ^+	.52 $\pm$.14

FIGURE CAPTIONS

Fig. 1 : Set-up of the NA3 spectrometer for this experiment.

Fig. 2 : Structure of the inhomogenous beam-dump.

Fig. 3 : a) Impulsion spectra (particle/GeV/incident pion).
b) Positive to negative ratio vs. momentum.

Fig. 4 : Mass spectra for
a) $\pi^+ \pi^-$ (showing K_S^0).
b) πp (showing Λ).
c) 3 pions (showing $K_{\pm}$).
d) $\Lambda \pi$ (showing E).

Fig. 5 : Momentum spectra for various particles.

Fig. 6 : Radial distribution for π , K_S^0 , Λ (arbitrary unit).

Fig. 7 : Ratio rate (220 cm)/rate (200 cm) vs. radius.

0 5m

FIG. 1

FIG. 2

FIG. 3a

FIG. 3b

a) $\pi^+\pi^-$ mass (GeV/c')

b) $\rho\pi$ mass (GeV/c')

c) 3π mass (GeV/c')

d) $\Lambda\pi$ mass (GeV/c')

FIG. 4

FIG. 5

FIG. 6

FIG. 7